STRUCTURAL CHARACTERISTICS OF THE HAIR OF MAMMALS

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THE microscopic structures in the hairs of mammals offer certain definite and unchanging characteristics which have been found useful for the purposes of identification.[1] The present paper aims to be an answer to numerous inquiries which the writer has received regarding: (1) the structure of a large number of mammal hairs, with especial reference to the possibility of systematically classifying them upon some morphologically accurate basis; (22) the relationships between the various elemental structures of the hair shaft; and (3) the methods employed in the preparation of the hairs for microscopic analysis.

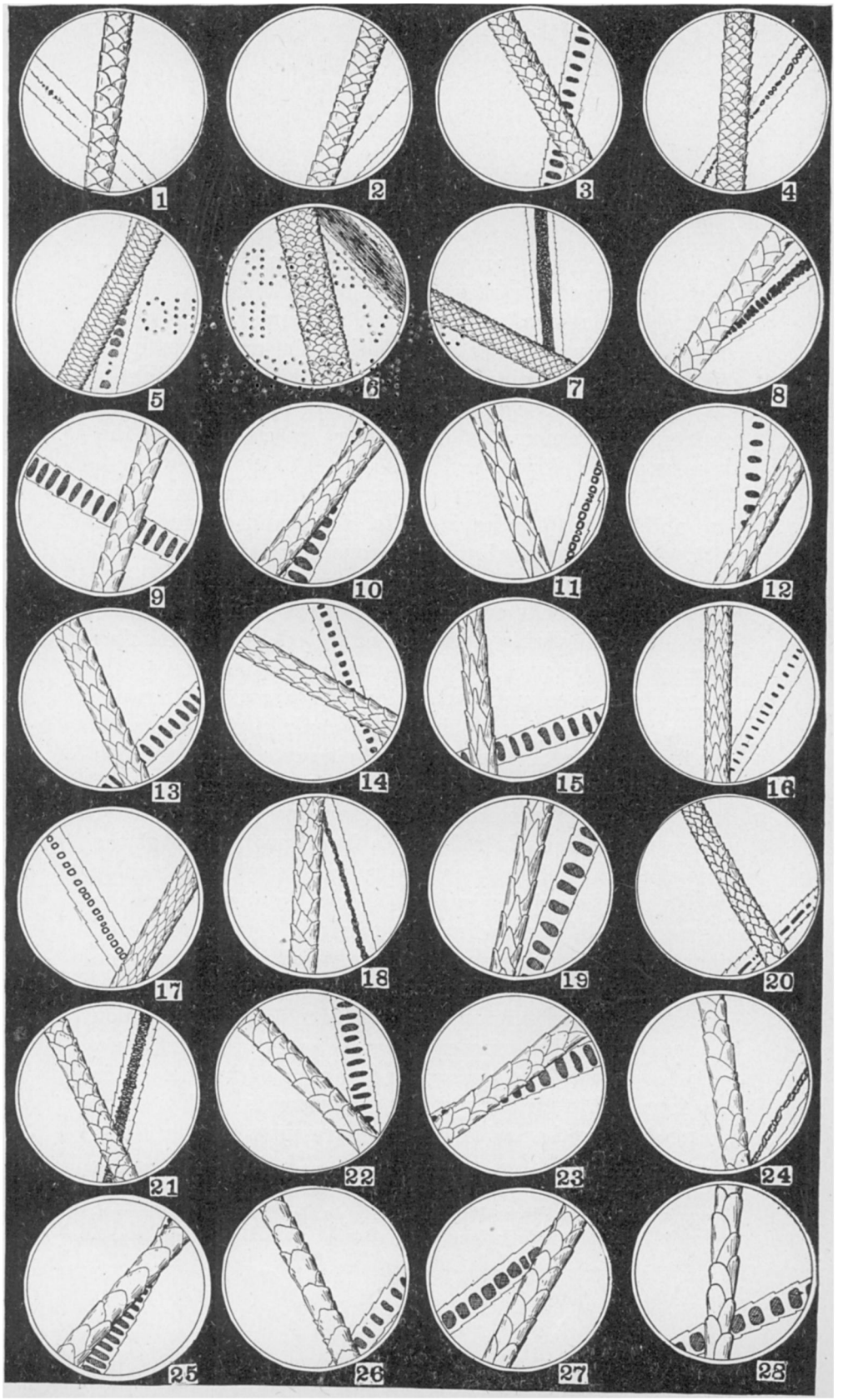
The primary development of the hair begins as a localized proliferation of the cells of the outermost layer of the skin, known as the epidermis, forming a dense aggregation of cells which elongates downward into the corium, or dermis, beneath. Directly underneath this downward-elongated, flask-shaped depression of the cells of the epidermis there is formed a dense mass composed of cells of the corium, or dermis, which ultimately becomes the papilla of the hair (*P*, Fig. 178). The flask-shaped depression now becomes lined with cells of the epidermis, and is called the follicle. The epithelial contents of the growing follicle elongate into an avial strand of fusiform, spindle cells, which later undergoes keratinization, or becomes horny, and forms the hair shaft. The lower portion of the shaft expands into a bulb which en-

[1] Hausman: (1) "The Microscopic Identification of Commercial Fur Hairs," *Scientific Monthly*, Jan., 1920, pp. 70–78; (2) "A Micrological Investigation of the Hair Structure of the Monotremata," *Am. Journal of Anatomy*, Sept., 1920, (3) "The Microscopic Identification of Mammal Hairs Used in the Textile Industry," *The Scientific American*, Feb. 21, 1920.

wraps the papilla (Fig. 178). The shaft elongates upward, and emerges through the epidermis, an aperture thereafter known as the mouth of the follicle, and continues to grow, the growth being exclusively confined to the bulbous lower, or proximal portion of the shaft. Here the conversion of matrix cells into keratinized hair shaft cells continually progresses. Mammal hairs are in general either circular or elliptical in cross section.[2] Those which are circular are straight, or but slightly curved, while those of elliptical cross section are curly or kinky, the amount of curl being dependent upon the flatness of the ellipse.

The hair shaft consists of four structural units (Figs. 167 and 168): (1) the *medulla,* sometimes termed the pith, from a somewhat analogous structure in plant stems, and which is built up of many shrunken and variously disposed cells or chambers, representing dried and cornified epithelial structures connected by a branching filamentous network, which sometimes completely fills the medullary column, but which is interrupted in many cases; (2) the *cortex,* or shell of the hair shaft, surrounding the medulla, and composed of elongate, fusiform cells or hair-spindles, coalesced together into a horny, almost homogeneous, hyaline mass and forming in many cases, where the medulla is reduced, a large proportion of the hair shaft; (3) the *pigment granules,* to which the color of the hair is primarily due (though in some hairs the pigment is diffuse and not in granular form), scattered about within or between the hair spindles, and in some hairs arranged in definite patterns; and (4) the *cuticle,* or outermost integument of the hair shaft, lying upon the cortex, and composed of imbricated, thin, hyaline, colorless scales of varying forms and dimensions. It is the forms, relationships, and measurements of these four elements, together with the measurements of the diam-

[2] The pioneer work in the relation of the shape of the cross section of human hair in its waviness to Dr. Pruner-Bey's "De La Chevelure comme Characteristique des Races Humaines, d'après des Recherches Microscopiques," in *Mémoires de la Société d'Anthropologie de Paris,* Vol. 2, p. 1.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eter of the hair shaft itself, in micra[3] which constitute the series of determinative criteria for each species of hair.

Medullas can be conveniently grouped, according to their forms, as they: (1) *discontinuous,* as in the hair of the Botta's pocket gopher (*Thomomomys bottæ*) (Fig. 3); (2) *continuous,* as in the hair of the kinkajou (*Cercoleptes caudivolvulus*) (Fig. 7); and (3) *fragmental,* as in the hair of the wombat (*Phascolomys ursinus*) (Fig. 64).

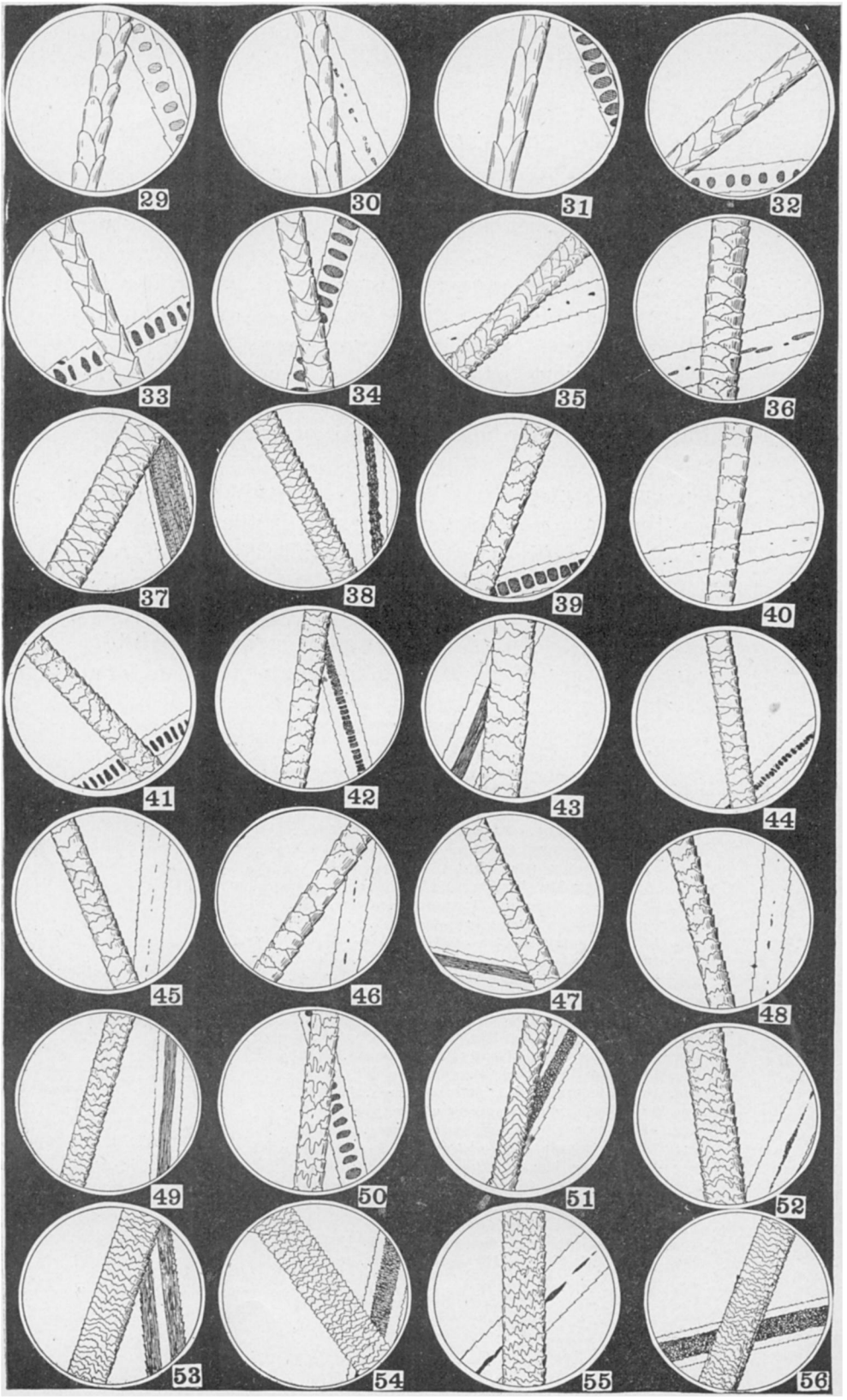
The cuticular scales fall readily into two well-marked types, the: (1) *imbricate,* represented in the hair of the civet (*Arctogalidia fusca*) (Fig. 1); and (2) *coronal,* represented in the hair of the majority of the bats, *e.g.,* the mastiff bat (*Molossus sinaloæ*) (Fig. 105).

The cortex element of the hair shaft structure exhibits few or no traces of the form of its component fusiform

EXPLANATION OF PLATE I

FIG. 1. Civet (*Arctogalidia fusca*), 21.00 μ.
FIG. 2. Pocket Kangaroo Rat (*Dipodomys m. nitratus*), 12.00 μ.
FIG. 3. Botta's Pocket Gopher (*Thomomys bottæ*), 25.50 μ.
FIG. 4. Coypu Rat (*Myocastor coypus*), 11.00 μ.
FIG. 5. Black Lemur (*Lemur makaka*), 20.00 μ.
FIG. 6. Chimpanzee (*Anthropopithecus troglodytes*), 119.00 μ.
FIG. 7. Kinkajou (*Cercoleptes caudivolvulus*), 34.00 μ.
FIG. 8. Rocky Mt. Jumping Mouse (*Zapus princeps*), 20.00 μ.
FIG. 9. Sierra Jumping Mouse (*Zapus trinotatus alleni*), 17.00 μ.
FIG. 10. Orolestes (*Orolestes obscurus*), 10.00 μ.
FIG. 11. Cacamixtli (*Bassariscus astutus flavus*), 17.00 μ.
FIG. 12. Striped Bandicoot (*Perameles bougainvillei bougainvillei*), 17.00 μ
FIG. 13. European Mole (*Talpa europœa*), 17.00 μ.
FIG. 14. Platypus (*Ornithorhynchus anatinus*), 8.00 μ.
FIG. 15. Star Nosed Mole (*Condylura cristata*), 25.50 μ.
FIG. 16. Pigmy Flying Phalanger (*Acrobates pygmœa*), 17.00 μ.
FIG. 17. Black Bear (*Ursinus americanus*), 27.00 μ.
FIG. 18. Red Kangaroo (*Macropus rufus*), 25.50 μ.
FIG. 19. Microgale (*Microgale dobsoni*), 18.80 μ.
FIG. 20. Aye aye (*Chiromys madagascariensis*), 24.00 μ.
FIG. 21. Koala (*Phascolarctos cinereus*), 20.40 μ.
FIG. 22. Dormouse (*Muscardinus pulcher*), 17.00 μ.
FIG. 23. House Mouse (*Mus musculus*), 17.00 μ.
FIG. 24. Gymnura (*Gymnura gymnura gymnura*), 19.00 μ.
FIG. 25. Woodland Jumping Mouse (*Napeozapus insignis insignis*), 21.00 μ
FIG. 26. Loir (*Glis glis glis*), 30.00 μ.
FIG. 27. Rat (*albino*) (*Mus norvegicus*), 17.50 μ.
FIG. 28. Hoy's Shrew (*Microsorex hoyi*), 18.00 μ.

[3] One micron (μ) is 1/1,000 of a millimeter, or circa 1/254,000 of an inch.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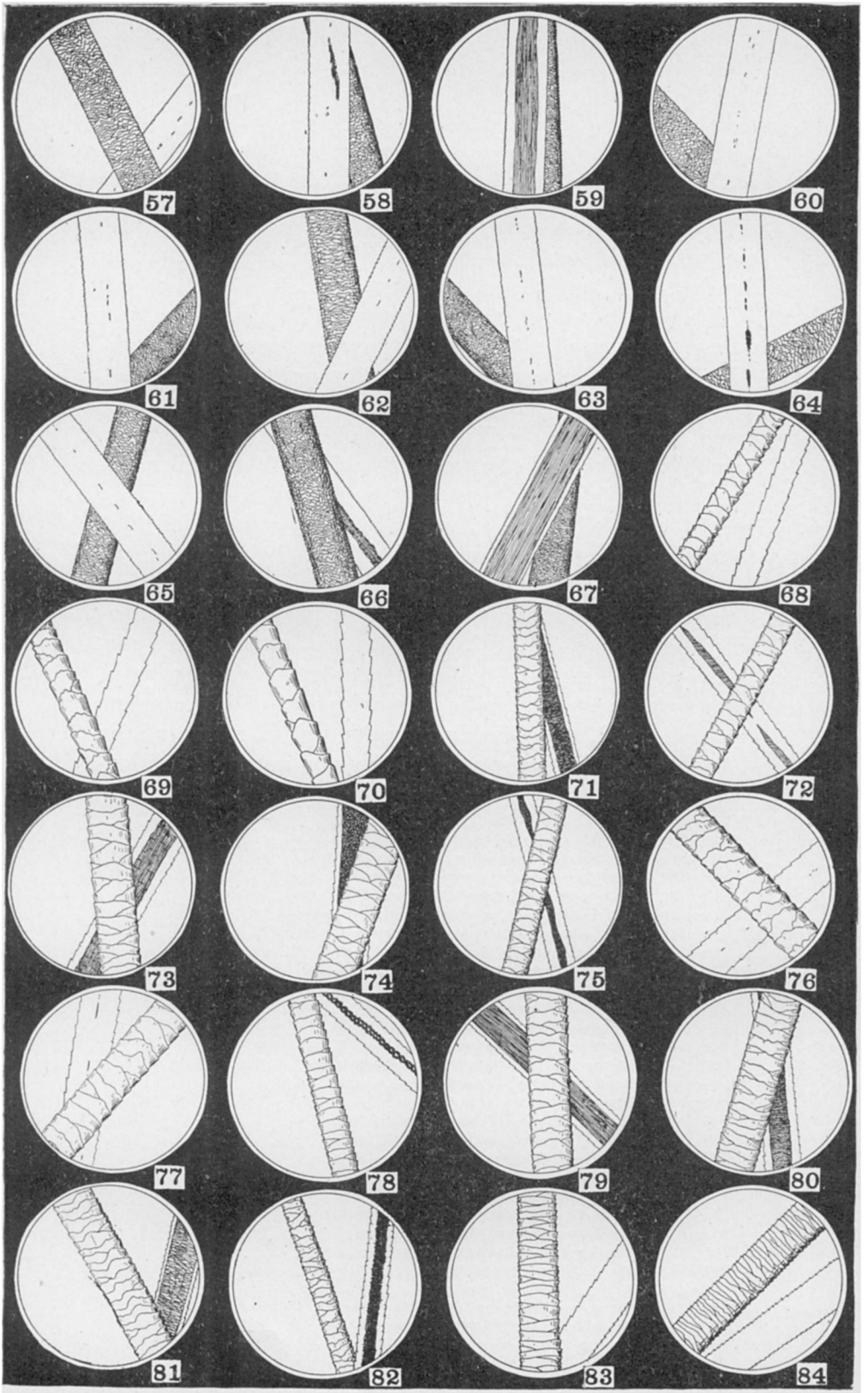
cells, or hair spindles, except under dissociative treatment with caustic soda, caustic potash, or acids of various sorts, and hence is of very little value as a criterion for determining the species of the hair.

The coloring matter, or pigment, of the hair shaft is either distributed diffusely and homogeneously throughout the cortex, or exists as an aggregation of granules between or within the fusiform cortical cells, or hair tween or within the fusiform cortical cells, or hair spindles. Where the latter is the case the granules appear to be of definite form and mode of placentation for each species of hair. In many cases, it is believed that the characteristic patterns formed by the arrangement of the pigment granules, as well as the form of the granules themselves may offer a valuable character for identification. Figs. 190, 191, and 192 show respectively portions of the hair shafts of the mandril (*Cyanocephalus maimon*), badger (*Taxidea americana*), and wolverene (*Gulo luscus*), very highly magnified, illustrative of the differences which may exist in the configuration and ar-

EXPLANATION OF PLATE II

FIG. 29. Geogale (*Geogale aurita*), 12.00 μ.
FIG. 30. Potamogale (*Potamogale velox*), 10.10 μ.
FIG. 31. Golden Mole (*Amblysomus corriæ*), 13.00 μ.
FIG. 32. Heliophobius (*Heliophobius kapiti*), 15.00 μ.
FIG. 33. Marsh Shrew (*Neosorex palustris navigator*), 11.30 μ.
FIG. 34. Rock Runner (*Petrodromus tetradactylus*), 37.00 μ.
FIG. 35. Speke's Jumping Mouse (*Pectinator spekii*), 25.00 μ.
FIG. 36. Walrus (*Trichechus rosmarus*).
FIG. 37. American Wapiti (*Cervus canadensis*), 94.00 μ.
FIG. 38. Mongoose Lemur (*Lemur mongoz*), 20.00 μ.
FIG. 39. Colugo (*Galeopithecus volans*), 20.50 μ.
FIG. 40. Coendou (*Coendou sanctæmartæ*), 25.00 μ.
FIG. 41. Flying Squirrel (*Sciuropterus volucella*), 11.70 μ.
FIG. 42. Bactrian Camel (*Camelus bactrianus*), 34.00 μ.
FIG. 43. Tiger (*Felis tigris*), 68.00 μ.
FIG. 44. Bruce's Dassie (*Procavia brucei rudolphi*), 22.00 μ.
FIG. 45. Dassie (*Procavia capensis*), 25.50 μ.
FIG. 46. Coendou (*Coendou mexicanus*), 38.00 μ.
FIG. 47. Proboscis Monkey (*Nasalis larvatus*), 47.60 μ.
FIG. 48. Spider Monkey (*Ateles geoffroi*), 32.00 μ.
FIG. 49. Great Gray Kangaroo (*Macropus giganteus*), 25.50 μ.
FIG. 50. Common Dasyure (*Dasyurus viverrinus*), 17.00 μ.
FIG. 51. Capybara (*Hydrochærus capybara*), 34.00 μ.
FIG. 52. Small Three-Spined Tenrec (*Hemicentetes varicgatus*), 28.00 μ.
FIG. 53. Unau (*Cholœpus capitalis*), 68.00 μ.
FIG. 54. European Porcupine (*Hystrix cristata*), 140.00 μ.
FIG. 55. Spiny Anteater (*Tachyglossus hystrix*), 103.00 μ.
FIG. 56. Agouti (*Dasyprocta urucuna*), 150.00 μ.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rangement of the pigment granules. There seems to be also a wide variation in color value and color depth of the pigment granules, a variation which is especially well brought out by the use of reflected light, or of dark field illumination. These methods of examination will be explained later.

In a recent contribution to the structure of the mammalian hair[4] the author has pointed out that mammal hairs may be conveniently classified, on the basis of the configuration of the cuticular scales and medulla, as follows:

CUTICULAR SCALES

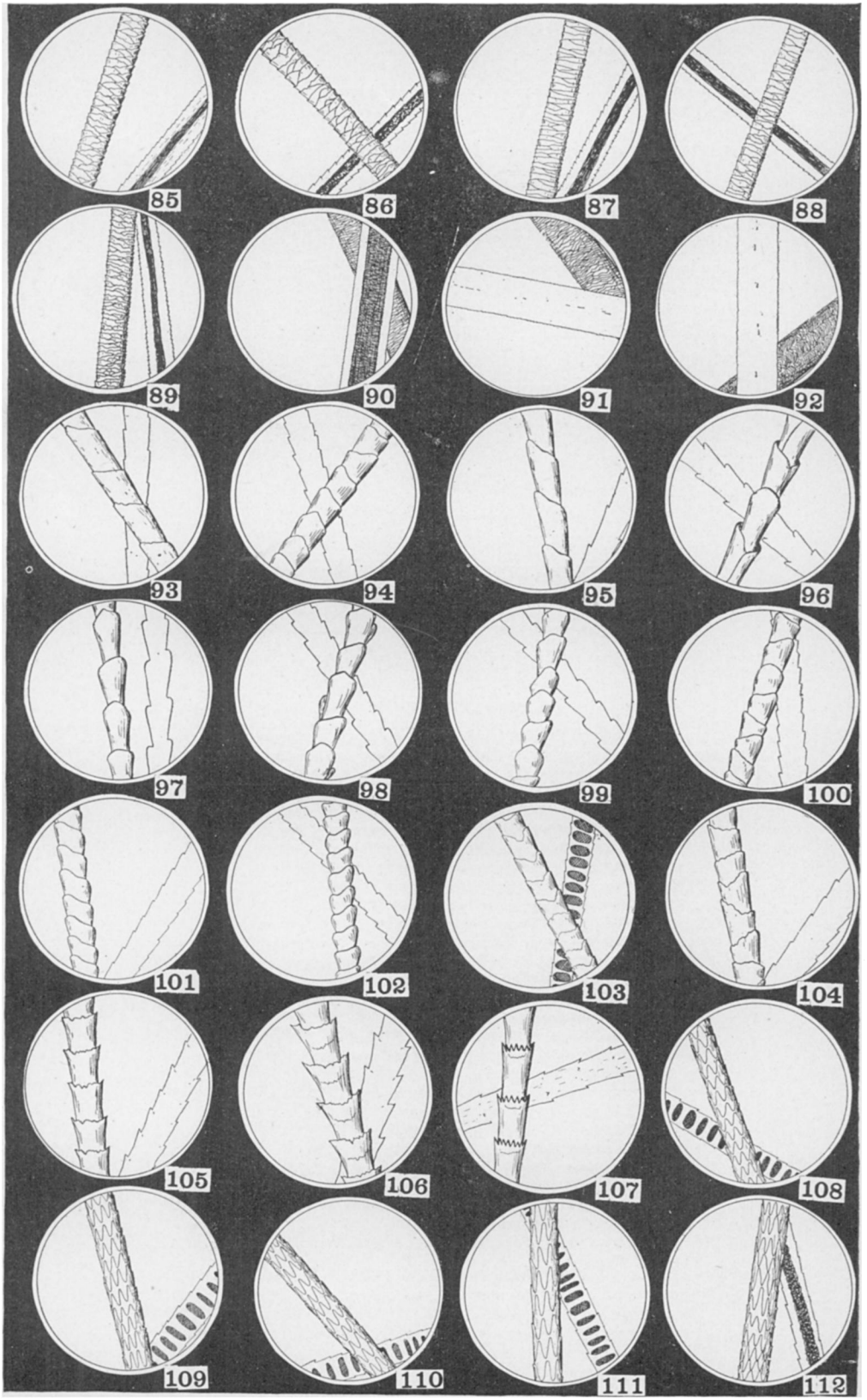
I. *Imbricate*

1. Ovate, represented by Figs. 1 to 7
2. Acuminate, represented by Figs. 8 to 20
3. Elongate, represented by Figs. 21 to 35
4. Crenate, represented by Figs. 36 to 67
5. Flattened, represented by Figs. 68 to 92

EXPLANATION OF PLATE III

FIG. 57. African Elephant (*Loxodonta africana capensis*), 80.00 μ.
FIG. 58. Ethiopian Aard Vark (*Orycteropus æthiopicus*), 252.00 μ.
FIG. 59. Hyena (*Hyæna hyæna schillingsi*), 122.00 μ.
FIG. 60. Richard's Seal (*Phoca richardi*), 232.00 μ.
FIG. 61. Two-Horned Rhinoceros (*Diceros bicornis bicornis*), 147.00 μ.
FIG. 62. Brush-Tailed Porcupine (*Ætherura africana*), 50.00 μ.
FIG. 63. Long-Tailed Pangolin (*Manis macrura*), 181.00 μ.
FIG. 64. Wombat (*Phascolomys ursinus*), 76.50 μ.
FIG. 65. Cape Aard Vark (*Orycteropus capensis*), 216.00 μ.
FIG. 66. Dinomys (*Dinomys brannicki*), 120.00 μ.
FIG. 67. Wild Boar (*Sus scrofa*), 680.00 μ.
FIG. 68. Two-Toed Anteater (*Cyclothurus didactylus*), 17.00 μ.
FIG. 69. Black-Faced Bat (*Mclanycteris melanops*), 10.00 μ.
FIG. 70. Small Long-Tongued Fruit Bat (*Macroglossus minimus*), 13.00 μ.
FIG. 71. Chevrotain (*Tragulus boreanus*), 51.00 μ.
FIG. 72. Llama (*Lama glama*), 32.00 μ.
FIG. 73. Fox Terrier, 98.60 μ.
FIG. 74. Ingraham's Hutia (*Capromys ingrahami*), 76.50 μ.
FIG. 75. Jersey Cow, 42.50 μ.
FIG. 76. American Bison (*Bison americanus*), 77.00 μ.
FIG. 77. Manatee (*Manatus latirostris*), 136.00 μ.
FIG. 78. Pinche (*Midas oedipus*), 40.00 μ.
FIG. 79. Boschbok (*Tragelephus sylvaticus*), 119.00 μ.
FIG. 80. Sumatran Chevrotain (*Tragulus napu*), 55.70 μ.
FIG. 81. Hispid Pocket Mouse (*Perognathus hispidus*), 127.00 μ.
FIG. 82. Squirrel Monkey (*Chrysothrix sciurea*).
FIG. 83. Agouti (*Dasyprocta variegata*), 127.50 μ.
FIG. 84. Tamandua (*Tamandua tetradoctyla etensis*), 85.00 μ.

[4] Hausman: "A Micrological Investigation of the Hair Structure of the Monotremata," *Am. Journal of Anatomy*, Sept., 1920.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II. *Coronal*

1. Simple, represented by Figs. 93 to 102
2. Serrate, represented by Figs. 103 to 107
3. Dentate, represented by Figs. 108 to 113

Medullas

I. *Discontinuous*

A. Simple

1. Ovate, represented by Figs. 114 to 126
2. Elongate, represented by Figs. 127 to 128
3. Flattened, represented by Figs. 129 to 135

B. Compound

1. Ovate, represented by Fig. 136
2. Flattened, represented by Fig. 137

II. *Continuous*

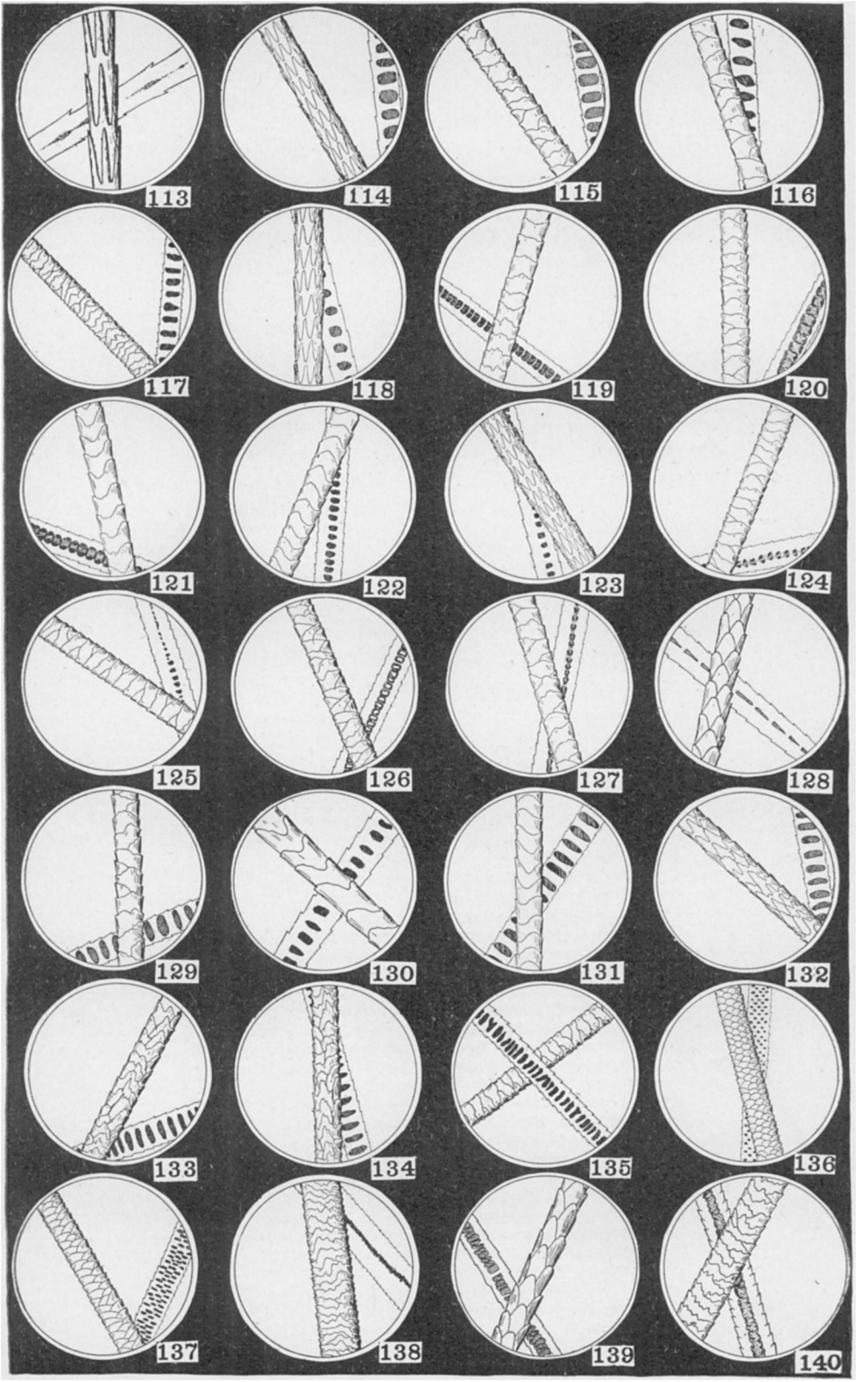
1. Nodose, represented by Figs. 138 to 147
2. Homogeneous, represented by Figs. 148 to 153

III. *Fragmental*

Represented by Figs. 115 to 166

EXPLANATION OF PLATE IV

Fig. 85. Gorilla (*Gorilla gorilla*), 37.40 μ.
Fig. 86. Virginia Deer (*Odocoileus americanus*).
Fig. 87. Sifaka (*Propithecus coronatus*), 30.00 μ.
Fig. 88. Woolly Monkey (*Lagothrix infumatus*), 30.00 μ.
Fig. 89. Orang (*Simia satyrus*), 144.50 μ.
Fig. 90. Agouti (*Dasyprocta fuliginosa*), 190.00 μ
Fig. 91. Barbirussa (*Barbirussa alfurus*), 93.00 μ.
Fig. 92. Peccary (*Dicotyles tajuca*), 407.00 μ.
Fig. 93. Yapock (*Chironectes panamensis*), 11.30 μ.
Fig. 94. Natalus (*Natalus mexicanus*), 11.00 μ.
Fig. 95. Porto-Rican Bat (*Chilonycteris parnelli portoricensis*), 8.50 μ.
Fig. 96. Hammer-Headed Bat (*Eupomorphorus anurus*), 11.00 μ.
Fig. 97. Bicolored Leaf-Nosed Bat (*Hipposiderus fulvus*), 8.50 μ.
Fig. 98. Indian Vampire Bat (*Lavia frons*), 12.00 μ.
Fig. 99. Leaf-Nosed Bat(*Rhinolophus hainanus*), 10.00 μ.
Fig. 100. Horseshoe Bat (*Rhinolophus acuminatus*), 10.00 μ.
Fig. 101. Pipistrelle (*Pipistrellus subflavus*), 6.80 μ.
Fig. 102. Java Vampire Bat (*Petalia capensis*), 10.00 μ.
Fig. 103. Cape Mole Rat (*Tachyoryctes rex*), 17.00 μ.
Fig. 104. Phyllops (*Phyllops falcatus*), 10.00 μ.
Fig. 105. Mastiff Bat (*Molossus sinaloae*), 9.00 μ.
Fig. 106. Wrinkled-Lipped Bat (*Nyctinomus bocagei*), 8.50 μ.
Fig. 107. Intermediate Bat (*Mormops intermedia*), 6.80 μ.
Fig. 108. Chief Pika (*Ochotona princeps*), 13.60 μ.
Fig. 109. Pika (*Ochotona figginsi*), 11.30 μ.
Fig. 110. Pika (*Ochotona wardi*), 11.30 μ.
Fig. 111. Alpine Chinchilla (*Lagidium pernarum*), 11.30 μ.
Fig. 112. Little Banded Anteater (*Myrmecobius fasciatus*), 20.40 μ.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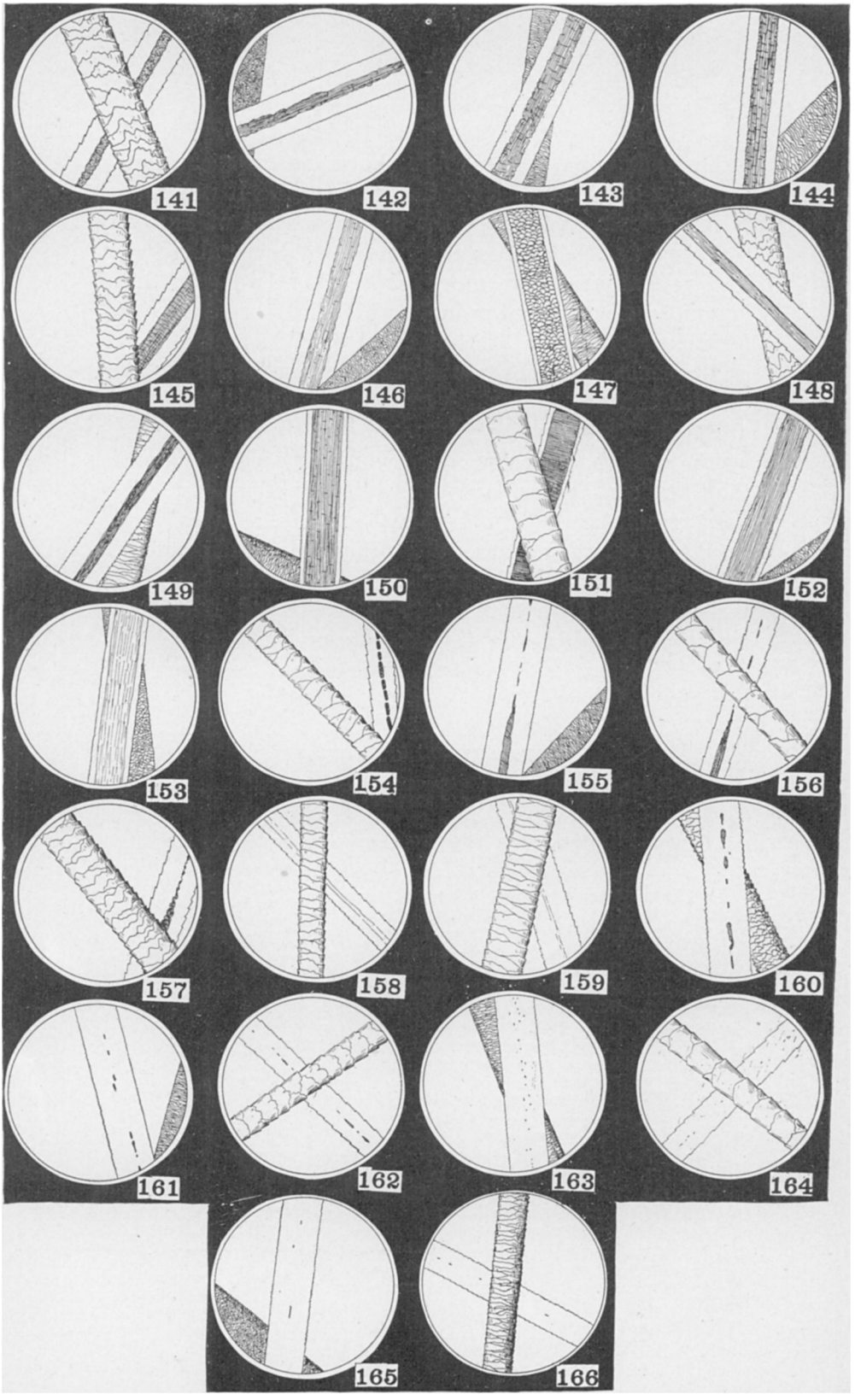
The hair type chosen to be shown as the most representative of each species is that type which, it was found, in most cases constitutes the major portion of the body covering, *i.e.*, the *fur,* or *under hair.* This usually underlies a comparatively more or less sparse growth of longer, coarser, stouter hair, which is termed the *protective,* or *over hair.* In typically aquatic mammals, such as the seals, walruses, etc., the protective hair is thicker than in those forms which are merely amphibious, such as the platypus, muskrats, beavers, etc. In such mammals as the whales, porpoises, etc., which are wholly aquatic, the fur hair has apparently vanished altogether. The only remaining hairs upon the body are, as a rule, confined to a very few stout stubs of hairs, located commonly in the region about the muzzle. In such hairs the cuticular scales are always of one type, illustrated by the muzzle hair of the dugong (*Dugong dugong*) (Fig. 159).

In identification, however, it is sometimes necessary to prepare for examination shafts of both the fur and the

EXPLANATION OF PLATE V

FIG. 113. European Otter (*Lutra vulgaris*), 10.00 μ.
FIG. 114. Chinchilla (*Chinchilla lanigera*), 16.00 μ.
FIG. 115. Dusky-Handed Tarsier (*Tarsius fuscus*), 13.00 μ.
FIG. 116. Elephant Shrew (*Macroscelides proboscideus*), 20.00 μ.
FIG. 117. Red Squirrel (*Sciurus hudsonicus*), 17.00 μ.
FIG. 118. Sewellel (*Aplodontia rufa*), 17.00 μ.
FIG. 119. Marsupial Mole (*Notoryctes typhlops*), 17.00 μ.
FIG. 120. Galeopterus (*Galeopterus gracilis*), 22.00 μ.
FIG. 121. Beecroft's Scale-Tailed Squirrel (*Anomalurus beecrofti*), 18.00 μ
FIG. 122. Viscacha (*Lagostomus maximus*), 41.00 μ.
FIG. 123. Black-Footed Ferret (*Putorius nigripes*), 20.40 μ.
FIG. 124. Nail-Tailed Wallaby (*Onychogale unguifera*), 18.50 μ.
FIG. 125. Foussa (*Cryptoprocta ferox*), 22.00 μ.
FIG. 126. Cavy (*Dolichotis salinicola*), 34.00 μ.
FIG. 127. Peters' Shrew (*Rhyncocyon petersi*), 26.00 μ.
FIG. 128. Racoon (*Procyon lotor*), 20.00 μ
FIG. 129. Philippine Tarsier (*Tarsius philippinensis*), 18.00 μ.
FIG. 130. Great Mole Rat (*Spalax typhlus*), 17.00 μ.
FIG. 131. Idiurus (*Idiurus zenkeri*), 9.10 μ.
FIG. 132. Nelson's Hare (*Romerolagus diazi*), 18.00 μ.
FIG. 133. Gray Rabbit (*Lepus nutalli mallurus*), 17.00 μ.
FIG. 134. Southern Varying Hare (*Lepus americanus virginianus*), 17.00 μ
FIG. 135. Black-Eared Marmoset (*Hapale jacchus*), 25.50 μ.
FIG. 136. Sennett Kangaroo Rat (*Perodipus sennetti*), 40.80 μ.
FIG. 137. Degu (*Octodon degus*), 34.00 μ.
FIG. 138. Agouta (*Solenodon paradoxus*), 83.00 μ.
FIG. 139. Canada Lynx (*Lynx canadensis*), 19.00 μ.
FIG. 140. European Hedgehog (*Erinaceus europeus*), 85.00 μ.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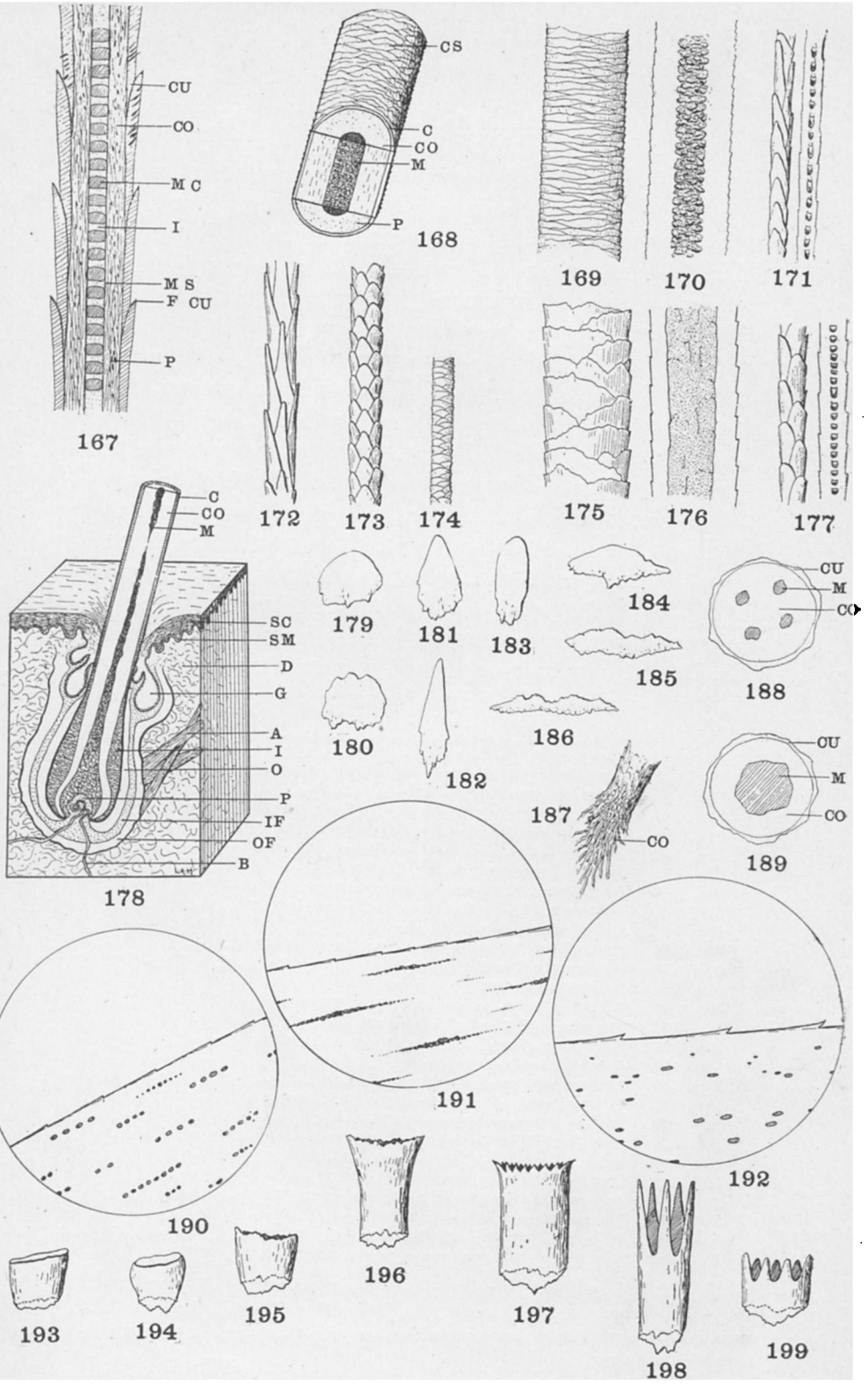
protective hair. And since the structural elements in these two types of hair usually differ considerably, a greater number of distinctive characters is thus available for comparison. However, the greater thickness and deeper pigmentation of the protective hair shafts make them much more difficult to work with than the finer, clearer fur hairs. Moreover, the scales of the protective hair are often worn off to such an extent as to make them also valueless as identification criteria. Figs. 175 to 177, and 169 to 171 show, represented to scale, the structure of the scales and medulla of the fur and protective hair of the skunk (*Mephitis mephitica*), and the European beaver (*Castor fiber*). The protective hair of mammals in general, in most cases, bears cuticular scales of the flattened or crenate type, and medullas of the continuous nodose or continuous homogeneous type.

In identifying hair species it is necessary to compare the scales and medulla from the same parts of the hairs[5]

EXPLANATION OF PLATE VI

FIG. 141. Polar Bear (*Thalarctos maritimus*), 68.00 μ.
FIG. 142. Hyena (*Hyæna hyæna bergeri*), 157.00 μ.
FIG. 143. Old World Tapir (*Tapirus terrestris*), 104.00 μ.
FIG. 144. American Tapir (*Tapirus americanus*), 74.00 μ.
FIG. 145. Langu (*Colobus caudatus matschei*), 88.00 μ.
FIG. 146. Central American Tapir (*Elasmognathus bairdi*), 96.00 μ.
FIG. 147. Rush Mouse (*Thryonomys gregorianus*), 165.00 μ.
FIG. 148. Hoffman's Sloth (*Cholœpus hoffmanni*), 68.00 μ.
FIG. 149. Ass (*Equus asinus*), 70.00 μ.
FIG. 150. Water Deer (*Hyomoschus aquaticum*), 122.00 μ.
FIG. 151. Thompson's Gazelle (*Gazella thompsoni nasalis*), 105.40 μ.
FIG. 152. Cape Giraffe (*Giraffa capensis*).
FIG. 153. Quagga (*Equus quagga bohmi*), 166.00 μ.
FIG. 154. Mongoose (*Helogale hirtula ahlselli*), 24.00 μ.
FIG. 155. Wart Hog (*Phacochœrus æthiopicus*), 357. 00 μ.
FIG. 156. Aard Wolf (*Proteles cristata*), 22.00 μ.
FIG. 157. Almiqui (*Solenodon cubanus*), 80.00 μ.
FIG. 158. Syrian Dassie (*Procavia syriacus*), 31.00 μ.
FIG. 159. Dugong (*Dugong dugong*), 1177.00 μ.
FIG. 160. Hair Seal (*Otaria jubata*), 105.00 μ.
FIG. 161. Indian Elephant (*Elephas indicus*), 200.00 μ.
FIG. 162. Coendou (*Cœndou mexicanus*), 38.00 μ.
FIG. 163. Antarctic Seal (*Hydrurga leptomyx*), 185.00 μ.
FIG. 164. Vicuna (*Lama vicuna*), 11.00 μ.
FIG. 165. Malayan Pangolin (*Manis javanica*), 290.00 μ.
FIG. 166. Mammoth (*Elephas primigenius*), from Alaska, 50.00 μ.

[5] The fur hair of many species of mammals varies upon different parts of the body, sometimes with respect to the configuration of the scales and medulla. Hence samples for comparison must be taken, as far as possible, from the same regions.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EXPLANATION OF PLATE VII

FIG. 167. Longitudinal section through an ideal generalized mammalian hair, of the discontinuous medulla variety, to show the relation of its structural elements.

CU, cuticle,
CO, cortex,
MC, medullary cell or chamber,
I, interstitial medullary space,
MS, medullary shaft or column,
FCU, free ectal edge of cuticular scale,
P, pigment granules.

FIG. 168. Stereogram of ideal generalized mammalian hair of the continuous medulla variety.

CS, cuticular scales,
C, cuticle,
CO, cortex
M, medulla,
P, pigment granules.

FIG. 169. Protective hair of European Beaver (*Castor fiber*) to show cuticular scales.

FIG. 170. Protective hair of European Beaver (*Castor fiber*) to show medulla.

FIG. 171. Fur hair of European Beaver (*Castor fiber*).

FIG. 172. Fur hair of Platypus (*Ornithorhynchus anatinus*) just above the mouth of the follicle.

FIG. 173. Fur hair of Platypus (*Ornithorhynchus anatinus*) one third of the distance from the base to the tip.

FIG. 174. Fur hair of Platypus (*Ornithorhynchus anatinus*) near the distal extremity, or tip.

FIG. 175. Protective hair of Skunk (*Mephitis mephitica*) to show cuticular scales.

FIG. 176. Protective hair of Skunk (*Mephitis mephitica*) to show medulla.

FIG. 177. Fur hair of Skunk (*Mephitis mephitica*).

FIG. 178. Stereogram of an ideal generalized mammal hair in its follicle.

C, cuticle,
CO, cortex,
M, medulla,
SC, stratum corneum of epidermis,
SM, stratum malphigii of epidermis,
D, dermis, corium,
G, sebaceous gland,
A, muscles which erect the hair shaft,
I, inner layer of root sheath,
O, outer layer of root sheath,
P, papilla,
IF, inner layer of follicle,
OF, outer layer of follicle,
B, blood and nerve supply to the bulb of the hair.

FIGS. 179 to 186. Various types of imbricate scales (referred to in text).

FIG. 187. Hair shaft showing teased-out cortical element.

CO, cortical cells or hair spindles.

FIG. 188. Transverse section through hair with compound medulla.

CU, cuticle,
M, medulla,
CO, cortex.

FIG. 189. Transverse through a hair with simple or single medulla.

CU, cuticle,
M, medulla,
CO, cortex.

FIG. 190. Portion of shaft of fur hair of Mandril (*Cyanocephalus maimon*) to show the configuration and disposition of the pigment granules.

FIG. 191. Portion of the shaft of the protective hair of the Badger (*Taxidea americana*) to show the configuration and disposition of the pigment granules.

FIG. 192. Portion of the shaft for the fur hair of Wolverine (*Gulo luscus*) to show the configuration and disposition of the pigment granules.

FIGS. 193 to 199. Various types of corneal scales (referred to in text).

under examination, since the form of the scale (more especially) undergoes alteration from the base to the tip of the hair shaft. As a rule the scales at the base of the hair are of greater longitudinal than transverse diameter, while the converse is true of the scales at the tip of the shaft. Figs. 172, 173 and 174 illustrate the nature of the change in form which is normally met with in the hairs of mammals as it occurs in the fur hair of the platypus (*Ornithorhynchus anatinus*). This modification in the form of the scales is believed to be due to the increasing amount of wear to which the hair shaft is subjected the farther away it is pushed from the follicle. That external friction is the cause of scale alteration in form is likewise suggested by the fact that the stiffest hairs possess, usually, scales of a much flattened type (cf. Figs. 57 to 67, inc.), while the finer hairs show the delicate, free ectal edges of the scales unchanged for at least the proximal three fourths of the length of the shaft. This is especially well illustrated in the hair of the bats, notably in such species as the mastiff bat (*Molossus sinaloæ*) (Fig. 105); the wrinkled-lipped bat (*Nyctinomus bocagei*) (Fig. 106); and the intermediate bat (*Mormops intermedia*) (Fig. 107).

The fur hairs shown in the plates[6] were chosen with the view of bringing out most clearly the nature of the forms of the simple varieties of scales and medullas, and of their various common modifications, as they exist one third of the distance from the mouth of the follicle to the top of the hair shaft. For convenience, therefore, the scales and medulla in this portion of the hair shaft have been termed *mature scales* and *mature medulla.* The scales at the distal extremity of the hair shaft, whose modification in form is considered to be the result of attrition, are called the *attritional scales,* and the pinched out medulla of the same region, the *fragmentary medulla.*

Inasmuch as the hair shafts represented in the plates

[6] The fur hair shown in the plates were taken, where possible, from the region of the median line of the dorsum, just below, *i.e.*, caudad of, the shoulders.

vary so widely in diameter (6.80 μ in the hair of the intermediate bat (*Mormops intermedia*) (Fig. 107); and 1,177 μ in the hair of the dugong (*Dugong dugong*) (Fig. 159), to draw them to the same scale, and at the same time to make the smaller hairs of sufficient size to show clearly the cuticular scales and medullas, was obviously impracticable. The arbitrary expedient was therefore adopted of drawing all the hairs whose diameters were equal to, or less than, 50 μ to one size, and drawing all those hairs whose diameters were greater than 50 μ to another size. In the figures the latter hairs are represented as being slightly greater in diameter. Such a division into coarse and fine hairs is not without its basis in common use, for it was found that as hairs are greater or less than 50 μ in diameter they are called respectively coarse or fine, or stiff and soft, by perhaps the majority of persons. The true spines form still a third division, with which, however, we shall have nothing to do.

Such an arbitrary representation of hair shafts, however, affords no appreciation of the relative or actual magnitudes of the hairs. In order that this might be had, therefore, the actual diameter of the fur hair of each species, in micra, is given after the name in the explanation of the plates. In each case this, obviously, is approximate only, the result of averaging a large number of individual measurements. It was found that the diameters of the hair shafts of any given individual vary considerably, and that a somewhat less range of variation occurs among the averages of different individuals of the same species. Hence it is inferred that only a meager amount of significance should be attached to hair magnitudes, except possibly, in large averages, and between large groups, *i.e.,* families or genera.

It must also be borne in mind that the prepared hair shaft, underneath the microscope, does not reveal at any one time the complete contour of the cuticular scales, or medulla, as it is represented in the figures. This is due to the fact, that with the objectives of sufficiently high

power to resolve the scale outlines, or the structure of the medulla, but one portion of the cylindrical hair shaft can be brought into exact focus at a time. The objective must in focusing *follow around the hair,* as it were, up one side, and down the other, revealing, as it goes, the course of the outline of the scale, or of the irregularities of the medulla. The resulting curves are then drawn on the single plane of the paper, as though the hair had, by some means, been crushed out flat without distorting its structure. It is because of this rotundity of the various elements of the hair shafts that it is often impossible to secure adequate photomicrographs of hair shafts, since it is necessary to employ high-powered objectives with a consequent very limited focal depth. Moreover the various different indices of light refraction and reflection among the hyaline elements of the shaft produce, upon the finished photograph, various striations and markings of one sort and another, which have no analogue in the actual structure of the hair shaft itself. It is possible, however, that photomicrographs of small, highly magnified portions of the hair shaft, cortex may be very useful in determining the form and placentation pattern of the pigment granules.

The figures of the fur hairs are arranged with the simple form of each type of scale, or medulla, coming first, followed by its various common variations. The hair of the civet (*Arctogalidia fusca*) (Fig. 1) represents the simplest form of the imbricate scale, termed the ovate. Fig. 179 shows the normal appearance of a single isolated scale of this type. Figs. 2 to 7 show the commonest modifications which the ovate scale undergoes. Of all of the imbricate scales whose longitudinal axis is equal to, or greater than, the transverse axis, the ovate is the most common.

Between the ovate scale and the acuminate, no definite line of demarcation can be drawn. I have considered Figs. 8 and 9 to represent perhaps the simplest form of the acuminate type. Figs. 10 to 17 show scales of in-

creasing acuminateness, while Figs. 18 to 20 show curious anomalous varieties.

In Figs. 181 and 182 are shown two isolated acuminate scales of characteristic outline.

The elongate type of cuticular scale (Figs. 21 to 35) is one least often met with, especially in its typical form, as shown in Figs. 29 to 31. The simplest variety (Fig. 21) possesses a longitudinal axis only a trifle greater than the transverse one. Figs. 29 to 31 are the typical varieties, and Figs. 32 to 35 show forms difficult to group. They are, however, tentatively put with the elongate forms. A single dissociated elongated scale is shown in Fig. 183.

By far the commonest types of scale which one encounters are the crenate and flattened types. The former are illustrated by Figs. 36 to 67. In this form of scale the transverse axis is much greater than the longitudinal, and the free ectal, or outermost edge of the scale is irregularly waved or crenulated. Of this type, a confusing multiplicity of variations occur. Some of the plainest and most easily interpreted of these are shown. Fig. 36 is considered to represent the simplest form. Scales like those shown in Figs. 57 to 67 are usually associated with the hairs of the greatest diameter, *i.e.*, the coarse, or stiff hairs, or bristles. This form is also characteristic of the majority of the spines. Two typical crenate scales, dissociated from the cortex, are represented by Figs. 185 and 186.

The flattened type is equally common and differs from the crenate only in exhibiting an ectal edge smooth and comparatively free from sudden irregularities. The longitudinal axis, however, is frequently but little greater than the transverse one, as can be seen in such hairs as are represented by Figs. 69 and 70. Fig. 68 represents the simplest form, and Fig. 184 a single scale of the same type.

In the coronal scale we have a scale fundamentally different from the imbricate. Here the scale usually com-

pletely surrounds the hair. The cuticular portion of the hair may be likened to a pile of tall tumblers placed one within the other, the upper rims representing the free ectal edges of the scales. Isolated coronal scales of various types are represented in Figs. 193 to 199. Fig. 93 represents a form which may be regarded as one of the simplest of the coronal scales. An isolated scale of this form is also shown in Fig. 193. The numerous variations of this type of scale are usually in the direction of a more flaring and more irregular ectal edge, as can be seen by comparing Figs. 93 to 113, and Figs. 193 to 199.

The coronal scales may be subdivided into simple (Figs. 93 to 102), serrate (Figs. 103 to 107), and dentate (Figs. 108 to 113). The simple scales, as well as the serrate are the forms usually found among the bats, which are fairly constant in this regard. Figs. 106 and 107 represent, perhaps, the maximum of scale decoration among the mammals. These scales, isolated from the cortex, are shown in Figs. 196 and 197. The intermediate bat (*Mormops intermedia*) whose hair is illustrated by Figs. 107 and 197, possesses, possibly, the finest of mammalian hair. The shafts of the fur hair average 6.80 μ in diameter, and often shafts of as small a diameter as 4.30 μ can be found. In these hairs, apparently, the cuticle has become greatly thickened, and the medulla has been lost. This seems to be true of the majority of the bats, more particularly of those bearing the serrate type of cuticular scales. The dentate type of scale is not found among bats, but seems to be scattered among several orders of mammals. It occurs most frequently among the members of the glires, or rodents. The simplest form is shown in Fig. 108, and other typical forms in Figs. 109 to 112. There seems to be not a great range of variation in this type of scale, the majority of species which bear this type of hair approximating very closely to the forms shown in Figs. 109 to 112. Fig. 113, however, shows an anomalous form of scale characteristic of both the American and European species of otter. In

this form the scale reaches its greatest length, as can be seen by the isolated scale, Fig. 198. The shorter scale, of the usual dentate type is shown in Fig. 199.

Of the three great groups of medullas: the discontinuous, the continuous, and the fragmental, the first seems to be subject to the greatest range of modification. This has been subdivided into simple, and compound types. The simple, furthermore, can be grouped as: ovate, represented by Figs. 114 to 126, elongate, shown by Figs. 127 to 128, and flattened, illustrated in Figs. 129 to 135.

The ovate type, in its various modifications, is met with usually, in hairs of small diameter. Thus the hairs of the shrews, moles, small rodents, one or two bats, etc., possess hairs of ovate medullas. The form usually encountered is apt to be more nearly like those shown by Figs. 114 to 118, than like the remainder of the ovate types (Figs. 119 to 126). The latter, especially such partially fused forms as shown in Figs. 120 and 121, are infrequently seen.

Still less common than these forms are the forms of the elongate medullas (Figs. 127 to 128). These must not be confused with the various fragmental types (Figs. 155 to 166). In the latter the divisions do not represent regularly placed cells or chambers as in the former.

The compound medullas, at least in the fur hairs, are the least common of all. Two varieties can be easily distinguished; the cells of one being ovate (Fig. 136), and the cells of the other flattened (Fig. 137). No instances of elongate cells were observed.

The continuous medulla (Figs. 138 to 153) seems to be the one characteristic of more than half of mammal hairs, particularly of those which are greater than 50 μ in diameter. It is found in nearly all of the protective, or over hairs, and is present in all spines and bristles, in some portion of the shaft. Fig. 168 shows a hair of this type as it would appear if sectioned to show the longitudinal and transverse appearance of the continuous medulla. The whole interior of the medullary column or

shaft (*MS*, Fig. 167) is filled with an anastomosing mass of cornified filaments, which probably represent a closely compressed aggregation of small medullary cells (Fig. 178). A type of medulla in which the component cells are still preserved so that their individual nature can still be seen, is shown in Fig. 147. Two divisions of the continuous medulla can be readily recognized; the nodose (or irregular) (Figs. 138 to 147), and the homogeneous Figs. 148 to 153). Between these two forms, all sorts of intergradational varieties exist.

The fragmental medulla (Figs. 155 to 166) represents perhaps various stages in the reduction of this element of the hair shaft structure, and seems to have been derived from the continuous type. Where the medulla seems to be lacking altogether, minute traces can still be found in various portions of the hair shaft, particularly in the region just below the mouth of the follicle. Structural indications seem to suggest that the development of medullas is from the discontinuous, through the continuous, to the fragmental, and finally, as is the case in the bats, to no medulla at all.

To prepare hairs for microscopical examination care must be exercised that the reagents used in cleaning, staining, etc., do not soften the cuticle, and thus distort the form of the scales, or that the cover glass is not made to press too heavily upon the hair, and thus flatten it out, deforming both the cuticular scales and medulla as well.

The simplest treatment for scale examination consists in washing the hair thoroughly in a solution composed of equal parts of 95 per cent. alcohol and ether (or chloroform). The hair may then be dipped into pure ether, or chloroform, to insure rapid drying, and when thoroughly dry placed upon a slide and covered with a cover glass for immediate examination. Some hairs, *e.g.*, those of sheep of most varieties, the fur hair of the camels, and the protective hair of many of the bats, notably the silvery bat (*Lasionycteris noctivagans*), exhibit the scales very well after this simple treatment. The 8x or 10x eye-

piece, and the 4 mm. objective with transmitted light, preferably from a blued glass, or better, daylight glass, gives the best results. Indirect lighting, with the mirror swung to one side, may be used where the scale edges are not easily seen. Reflected light has been found excellent, but only in a very few cases.

With hairs like those of the rabbits and hares, shrews, moles, the fur hair of bats, and the like other manipulations of the hair must be brought into requisition. One of the most generally useful of the various staining preparations consists in immersing the hair, after its ether-alcohol bath, in a solution of gentian violet, methyl blue, methyl green, or safranin, in 95 per cent. alcohol. The stain is prepared by making up a saturated solution of the stains enumerated, and then diluting each with 95 per cent. alcohol to the desired degree of color depth, which must be empirically determined for each different species[7] of hair. The evaporation of the alcohol, which must be accomplished rapidly in a warm current of air from a bunsen flame, deposits in the depressions just ectad of each cuticular scale edge, a tiny bit of the stain, which therefore clearly outlines the contour of each individual scale. This method is difficult, and the writer has found that repeated trials with the same hairs were frequently necessary before satisfactory results were secured. In working with hairs it is better to use a tuft of 25 or 50, rather than try to work with but a few.

The preparation of the hair, is, however, of but slight importance compared with the manipulation of the proper lighting and the proper combination of objective and ocular. Where the cuticular scales remain obstinately invisible, or only faintly seen, various sorts of illumination must be tried; transmitted vertical light, transmitted oblique light, dark field illumination, reflected light, and polarized light. Dark field illumination,

[7] The writer is aware that "species of hair" is hardly admissible, yet the convenience must be the excuse for its use.

with the 1.8 mm. objective and 4x eyepiece was found excellent for a large number of hairs. It must be borne in mind that, in using this combination of immersion objective with the dark field illuminator, an oil connection must also be formed between the upper surface of the condenser and the lower surface of the slide.[8] Exigency of space forbids the descriptions of the various types of lighting which have been found most satisfactory with the various species of hairs. These must be empirically determined by each investigator. The degree of success obtained with the microscope usually depends as much upon the preparation of the instrument and its lighting, as upon the preparation of what is to go under it for examination.

For examination of the medulla all that has been said regarding lighting, etc., applies. However, the various treatments given the hair and used to render visible the cuticular scales, obscure the medulla. The simplest and most generally useful method of rendering the medulla clear, consists in reducing the visibility of the cuticular scales to as near zero as possible by mounting the hair, beneath the cover glass, in some light microscopical oil, such as oil of bergamot, of cedar, or origanum, of amber, of cloves, etc., after having washed it, as before, in the ether-alcohol solution. Such a treatment renders the hair, in effect, a glassy cylinder, within which the medulla can be clearly seen, provided the cortex is not thickly besprinkled with pigment granules, or rendered dark in color by diffuse pigment. Fortunately most of the fur hairs are lightly pigmented. Many of the protective hairs, however, are so heavily colored that the medulla is partially, or almost wholly, obscured.

Some of the finer hairs can be examined with advantage in a mount of clear water, or xylol. The best treat-

[8] For directions for all sorts of microscope manipulations, apparatus, microscopical principles, etc., consult Professor S. H. Gage's comprehensive "The Microscope, and Introduction to Microscopic Methods and to Histology," Ithaca, N. Y., 1917. A new edition of this valuable work is now ready to leave the press.

ment, however, was found to consist in washing the hair in the ether-alcohol, drying, immersing in xylol, and then mounting in very thin Canada balsam. This makes a permanent mount.

Lighting with the dark ground illumination was found to give the best results in the examination of the external configuration of the medulla.

In the case of hairs where the heaviness of the pigmentation obscures the medulla, or in compound-medullated hairs, or in those cases where an accurate knowledge of the form of the cross section of the medullary column is desired, it is necessary to prepare cross sections of the hair shaft, by the usual methods of imbedding in paraffin or celloidin.[9] Figs. 188 and 189 show the manner in which the form of the medulla is shown in transverse sections, as well as its relations to the thickness of the cortex and of the cuticle.

The methods used to make clear the medulla serve well also to reveal the pigment granules. In examination of the shaft for these tiny bodies the 1.8 mm. objective and the 10x eyepiece with the draw tube of the microscope extended its full length was found to be the lowest power which could be satisfactorily employed. Lighting with daylight glass and a 200-watt tungsten-filled bulb was apparently a necessity.

The cortex, because of its nearly homogeneous structure, was not found to exhibit characters which could be used as criteria for identification. Fig. 187 shows a hair macerated in caustic soda, and with the cortex teased out to show the distorted, elongated cortical cells, or hair spindles.

The use of caustics and strong acids for dissociating the cuticular scales is not recommended. The softening of the scales distorts their form and thus renders them useless for delicate determinative purposes.

It very often becomes necessary to distinguish the dis-

[9] For histological methods consult Professor M. F. Guyer's "Animal Micrology," Chicago.

tal from the proximal end of some one hair shaft. This can be done under the microscope, remembering: first that the image is reversed, and second, that the free edges of the cuticular scales lie always at the ectal, or distal portion of the scale, and so indicate the direction of the distal extremity of the hair. A much more simple method is to rub the hair in question between the thumb and finger, when it will always travel in the direction of the bulb, *i.e.,* in the direction of its proximal extremity. This fact that the free ectal edges of the cuticular scales develop in such a way that they are always directed outward from the animal, suggests that they may afford protection against the intrusion between the hairs, and so on to the skin itself, of foreign bodies, parasites, and water. Furthermore any such extraneous elements which may have gained entrance, apparently would tend to be worked outward away from the skin to the outer surface of the hair covering by the motions into which the hair is thrown by the movement of the muscles of the body during locomotion.

In preparing a series of animal hairs to be used as type specimens for determinative comparisons with unknown hairs it is well to have a series of slides prepared to show the medulla (mounted in balsam as previously directed), and another series of slides with the hairs mounted thereupon in dry cells[9] (washed in the ether-alcohol, and stained or not as each requires), to show the cuticular scales. Since this later method of preparing hairs seems to be attained with little success (too much dust gathering upon the hair, the fibers obscuring the sculpturings of the cuticular scales), it is better, perhaps, to keep a tuft of each species of hair in a small phial or double envelope, and make fresh preparations when necessary. Both the balsam-mounted slides and the untreated hair samples should be filed away following the classification scheme for the scales and medulla given in this paper. This facilitates the immediate selection of the particular group of hairs possessing the charac-

teristics of the unknown sample, and makes identification much easier and quicker. For each species of mammal samples of the hair from several regions of the body should be had, as well as samples of both the fur and protective hairs of various regions. From his own experience, however, the writer is well aware that this is an ideal more easily recommended than realized.